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Comparison of Chest Ultrasound and Standard X-Ray Imaging in COVID-19 Patients

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ABSTRACT

Purpose The COVID-19 pandemic poses new challenges for the medical community due to its large number of patients presenting with varying symptoms. Chest ultrasound (ChUS) may be particularly useful in the early clinical management in suspected COVID-19 patients due to its broad availability and rapid application. We aimed to investigate patterns of ChUS in COVID-19 patients and compare the findings with results from chest X-ray (CRX).

Materials and Methods 24 patients (18 symptomatic, 6 asymptomatic) with confirmed SARS-CoV-2 by polymerase chain reaction underwent bedside ChUS in addition to CRX following admission. Subsequently, the results of ChUS and CRX were compared.

Results 94 % (n = 17/18) of patients with respiratory symptoms demonstrated lung abnormalities on ChUS. ChUS was especially useful to detect interstitial syndrome compared to CXR in COVID-19 patients (17/18 vs. 11/18; $p < 0.02$). Of note, ChUS also detected lung consolidations very effectively (14/18 for ChUS vs. 7/18 cases for CXR; $p < 0.02$). Besides pathological B-lines and subpleural consolidations, pleural line abnormality (89 %; n = 16/18) was the third most common feature in patients with respiratory manifestations of COVID-19 detected by ChUS.

Conclusion Our findings support the high value of ChUS in the management of COVID-19 patients.

Background

At present, national health systems throughout the world are being overwhelmed by the amount of respiratory tract infections associated with the novel coronavirus 2019 (SARS-CoV-2) that can cause coronavirus disease 2019 (COVID-19). SARS-CoV-2 has proved to be highly contagious, spreading globally within a very short time and prompting the WHO to declare it a pandemic on March 11, 2020.

Referring to positive-stranded RNA viruses of the *Coronaviridae* family, SARS-CoV-2 demonstrates a high sensitivity to the human airway epithelial cells, resulting in a variety of respiratory symptoms including acute respiratory distress syndrome occurring in up to 5 % of cases due to its cytopathic effects [1]. Given the explosive spread of the virus as well as the fact that an estimated 5 % of patients with SARS-CoV-2 infections have severe or critical symptoms that require hospitalization [2], clinicians are facing an enormous logistical and medical challenge, including the appropriate choice of diagnostic imaging methods. Thoracic imaging has turned out to be an essential part for the diagnostic workup and clinical management of COVID-19 patients. In particular, computed tomography (CT) of the chest has been shown to be a highly efficient tool and is the gold standard for the early detection of COVID-19 pneumonia according to several studies [3–5]. However, routine chest CT upon admission to the emergency room may not be available in most medical centers around the world and may expose patients with other upper respiratory tract infections or a potential mild course of COVID-19 to unnecessary radiation. Therefore, bedside diagnostic imaging is a desirable and rapid solution that may have great potential to be implemented in algorithms for the early clinical management of COVID-19 patients. Interestingly, conventional chest X-ray (CXR) may often fail to capture early signs of COVID-19 pneumonia such as ground-glass opacity [3]. In contrast, initial data from China and Italy may indicate that point-of-care chest ultrasonography (ChUS) might be more appropriate to diagnose patterns of interstitial syndrome and alveolar consolidations, and may even reach similar diagnostic accuracy as CT scans [6].

Therefore, point-of-care ChUS might constitute a rapid, cost-effective and safe imaging tool that may be positioned at the interface between CXR and chest CT. Here, we aim to describe patterns of ChUS in COVID-19 patients and systematically compare our findings with results from CXR.

Materials and Methods

Patients

24 patients with confirmed SARS-CoV-2 by RT-PCR were admitted to our university hospital from March to April 2020. CXR was performed as a standard radiologic investigation for the assessment of lung abnormalities. Furthermore, all patients underwent routine bedside ChUS following admission. In addition, clinical as well as laboratory data were recorded. Statistical tests were performed using the Chi-squared test, and p-values < 0.05 were considered significant. The retrospective data analysis was approved by a decision of the local ethics committee (№ 38/4/20).

Imaging techniques

Bedside ChUS was performed on Venue 50 and Logiq E9, GE Medical Systems, USA.

A standard ChUS protocol was used. In detail, patients were investigated by both linear (8.4–13.0 MHz) and convex probes (4.0–5.0 MHz) in supine and sitting position at six predetermined examination points (ventral, lateral and dorsal chest wall in apical and basal position, respectively). The ChUS assessment parameters included the amount (pathologic ≥ 3/field of view) and distribution of B-lines (unilateral, bilateral, focal, multifocal, confluent), pleural line abnormalities (unilateral, bilateral), consolidations (unilateral, bilateral, focal, multifocal, confluent), abnormal lung sliding and pleural effusions [6].

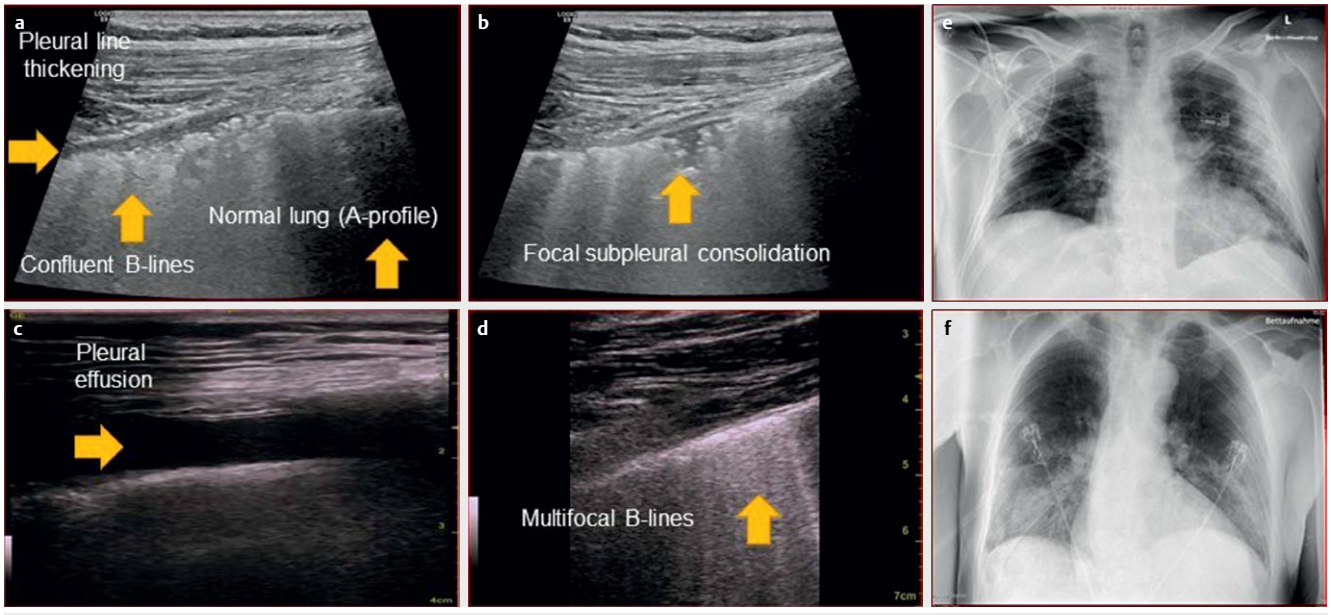
Depending on the clinical setting, CXR was performed either in the posterior-anterior and lateral position or in the antero-posterior position with findings described according to the glossary of the Fleischner Society [7]. CXR evaluation focused on the presence and distribution of hazy increased opacities, consolidations, and pleural effusions. The assessment of ChUS and CXR images was performed by two blinded investigators.

Results

The median age of patients was 65 years (range: 25–95 years) with 16 males and 8 females. The most common symptom was dyspnea (n = 14/24) followed by cough (n = 10/24) and fever (n = 7/24). 10 patients (42 %) required at least 2 liters of oxygen per minute and

▶ **Table 1** Clinical and laboratory characteristics of the 24 patients with confirmed SARS-CoV-2.

All patients, n = 24	**COVID-19, n = 18; SARS-CoV-2 carrier, n = 6**	
Males: females	16:8	
Median age, years (range)	65	(25–95)
Type of symptoms	18/24	(75 %)
Dyspnea	14	(58 %)
Cough	10	(42 %)
Fever	7	(29 %)
Chest pain	1	(4 %)
Oxygen inhalation		
< 2 L/min	14	(58 %)
≥ 2 L/min	10	(42 %)
Respiratory rate		
≤ 18/min	15	(62 %)
> 18/min	9	(38 %)
Laboratory tests		
WBCs × 10^9/L, median (range)	6.4	(2.0–19.0)
CRP mg/dl, median (range)	19	(0.3–164)
PCT ng/ml, median (range)	0.08	(0.01–0.4)
LDH U/L, median (range)	316	(108–882)
Status at last follow-up		
Alive	24	(100 %)
Dead	0	(0 %)



▶ **Fig. 1** **a-d**: pleural line thickening **a**, focal subpleural consolidation **b**, pleural effusion **c** and multifocal B-lines **d** as common findings revealed by ChUS, **e** ground-glass opacification and consolidation in the right upper lobe and left lower as well as upper lobe with peripheral distribution, **f** bilateral patchy consolidation predominantly in the lower zone with sparing of the right and left apex.

9 (37 %) demonstrated increased breathing frequency (> 18/min) at rest. Notably, 6 patients (25 %) were SARS-CoV-2 carriers and only admitted due to either general deterioration (n = 1) or co-morbidity (lymphoma, cholangiocarcinoma, stroke, bradycardic atrial fibrillation, and retinal detachment, respectively). Considering laboratory tests, the median values on the day of investigation were as follows: WBCs 6.4×10^9/L, CRP 19 mg/dl, PCT 0.08 ng/ml and LDH 316 U/L. None of the patients died during the period of this study. The clinical and laboratory characteristics of all patients are summarized in ▶ **Table 1**.

Of 18 COVID-19 patients, 17 (94 %) demonstrated pathologic B-lines with bilateral distribution in 14 (82 %) cases. For B-lines, multifocal appearance was predominantly found (10/17; 59 %) whereas confluent B-lines were only detected in two patients (▶ **Fig. 1a, d**). Of note, 16 of 18 patients (89 %) showed pleural irregularities that occurred most frequently bilaterally. In contrast to pleural irregularities, pleural thickening (▶ **Fig. 1a**) was less frequently detected (8/18; 44 %). Pulmonary consolidations were detected in 14 of 18 COVID-19 patients (77 %) demonstrating with mostly focal character (10/14) (▶ **Fig. 1b**), and an equal uni- and bilateral distribution (7/14 each). Again, no confluent pattern for consolidations was present as well. Along this line, abnormal lung sliding was observed only in 3 of 18 patients (17 %) and occurred only in cases with multifocal consolidations. 10 cases (56 %) showed small pleural effusions with a mostly bilateral manifestation (7/10) (▶ **Table 2**) (▶ **Fig. 1c**).

Regarding the anatomical distribution of lung abnormalities by ChUS, the lower lobe (9/18) or both the lower and the upper lobe (7/18) were predominantly affected, whereas isolated upper lobe involvement was observed in only one case. Interestingly, patients with both lower and upper lobe involvement demonstrated a more severe clinical and laboratory course of COVID-19 than the cases with isolated lobe affection: intermediate care unit admission (5/7 vs. 2/10); O2 ≥ 2 L/min (6/7 vs. 3/10); respiratory rate > 18/min (5/7 vs. 4/10); median WBCs, CRP, PCT and LDH (7.1 vs. 5.4×10^9/L; 87 vs. 29 mg/dl; 0.11 vs. 0.09 ng/ml and 372 vs. 322 U/L, respectively). However, due to the limited number of patients, no significant differences were found.

Of note, pathological findings were not seen on ChUS in 7 out of 24 patients (29 %). However, only one of these patients had COVID-19 whereas the remaining six cases were asymptomatic SARS-CoV-2 carriers.

Comparing the ChUS results to standard CXR (available for 23 out of 24 patients), the most common sign in COVID-19 patients (n = 18) was hazy increased opacity (▶ **Fig. 1e**) in 11/18 (61 %, $p < 0.02$ compared to B-lines on ChUS) cases followed by consolidations (▶ **Fig. 1f**) (7/18; 38 %; $p < 0.02$ compared to consolidations on ChUS), and pleural effusion (5/18; 28 %; $p = 0.09$ compared to ChUS) (▶ **Table 3**).

The lesions in CXR were predominantly present in the lower (8/18; 44 %) or in both the lower and the upper lobes (7/18; 39 %) and tended to be distributed bilaterally (13/18; 72 %). Of note, only 5/9 lesions (55 %) in the lower lobe and 4/7 lesions (57 %) in the upper and the lower lobe were detected by both ChuS and CXR, suggesting poor agreement between ChuS and CXR. Regarding asymptomatic SARS-CoV-2 carriers (CXR for 5/6 available), only 1/5 demonstrated local hazy increased opacity and none of them had consolidations.

Discussion

Currently, multiple challenges are associated with the management of the COVID-19 pandemic. Regarding thoracic imaging, rapid and cost-effective diagnostic tools are urgently needed to cope with the large number of patients. In our study, we investigated patterns

▶ **Table 2** Ultrasound findings of n = 18 COVID-19 patients.

COVID-19 patients	n = 18	
Pathologic B-lines	**17/18**	**(94 %)**
a. Unilateral	3/17	(18 %)
b. Bilateral	14/17	(82 %)
c. Focal	5/17	(29 %)
d. Multifocal	10/17	(59 %)
e. Confluent	2/17	(12 %)
Pleura irregularity	**16/18**	**(89 %)**
a. Unilateral	2/16	(13 %)
b. Bilateral	14/16	(87 %)
Pleura thickening	**8/18**	**(44 %)**
a. Unilateral	5/8	(57 %)
b. Bilateral	3/8	(43 %)
Pleural effusion	**10/18**	**(56 %)**
a. Unilateral	3/10	(30 %)
b. Bilateral	7/10	(70 %)
Pulmonary consolidation	**14/18**	**(77 %)**
a. Unilateral	7/14	(50 %)
b. Bilateral	7/14	(50 %)
c. Focal	10/14	(71 %)
d. Multifocal	4/14	(29 %)
e. Confluent	0/14	(0 %)
Abnormal lung sliding	**3/18**	**(17 %)**
a. Unilateral	2/3	(67 %)
b. Bilateral	1/3	(33 %)
Distribution of lung abnormalities		
a. Lower lobe	9/18	(50 %)
b. Upper lobe	1/18	(6 %)
c. Both lower and upper lobe	7/18	(38 %)
d. Neither upper nor lower	1/18	(6 %)

▶ **Table 3** X-ray findings of n = 18 COVID-19 patients.

COVID-19 patients	n = 18	
X-ray abnormalities		
a. Hazy increased opacity	11/18	(61 %)
b. Consolidation	7/18	(39 %)
c. Pleural effusion	5/18	(28 %)
Distribution of lung abnormalities		
a. Unilateral	3/18	(17 %)
b. Bilateral	13/18	(72 %)
c. Lower lobe	8/18	(44 %)
d. Upper lobe	1/18	(6 %)
e. Both lower and upper lobe	7/18	(39 %)
f. Neither upper nor lower	2/18	(11 %)

of bedside ChUS for the assessment of COVID-19 patients and compared them to findings of conventional CXR.

In fact, the vast majority of COVID-19 patients demonstrated lung abnormalities on ChUS. Notably, these results are in line with two other recent studies that investigated COVID-19 patients by ChUS [8, 9]. In particular, ChUS was especially informative for revealing different manifestations of interstitial syndrome. The same refers to the detection of lung consolidations by ChUS. In particular, consolidations in COVID-19 cases were characterized by a rather focal and mostly subpleural appearance presenting frequently not only in basal but also in apical parts of the lung. In conjunction with the frequent presence of alveolar consolidations, pleural line abnormalities were the third most common sign among patients with symptomatic COVID-19. Although it is difficult to directly correlate anatomical locations of lung abnormalities between ChUS and CXR without having chest CT imaging as an anatomical reference, our results suggest relatively poor agreement between ChUS and CXR for the anatomical locations of lung pathologies.

Recently, Peng et al. reported the rare presence of pleural effusion in 20 COVID-19 patients investigated by ChUS [6]. In contrast, our data provide evidence that small pleural effusions were present in almost half of COVID-19 patients and detected more often by ChUS compared to CXR. Regarding the anatomical distribution of involved lung lobes, ChUS predominantly showed affection of the lower lobes, but simultaneous lower and upper lobe involvement was also recorded. Simultaneous affection of the upper lobe was associated with a more severe clinical course as evidenced by frequent intermediate care unit admission, more severe dyspnea, and a higher rate of systemic inflammation. Thus, we conclude that US examinations should always involve apical parts of the lung independent of basal findings.

Interestingly, all six asymptomatic SARS-CoV-2 carriers showed no abnormalities on ChUS which was in accordance with CXR results. This aspect may be of interest especially in emergency departments where clinicians have to make decisions as to whether additional imaging modalities such as CXR or CT scans need to be employed, and ultimately whether the patient can be dismissed to ambulatory care or has to be admitted. Following the ongoing active exploration of the diagnostic role of ChUS in the COVID-19 pandemic, clinical and sonographic classification of COVID-19 pneumonia was recently suggested.[10].

Finally, the frequent finding of bilateral and multilobar lesions on ChUS in our study confirmed earlier observations by CT scans that peripheral subpleural distribution of lung lesions is frequently found in COVID-19 patients [3, 4, 11]. To that end, several studies could show the association of ChUS findings with CT abnormalities in direct comparison with each other [6, 8, 9]. Using chest CT as the reference standard, Lu et al. reported on the successful application of lung ultrasound score in COVID-19 patients with a diagnostic accuracy of 76.7 %, 76.7 % and 93.3 % for mild, moderate and severe lung lesions, respectively [12]. Despite all of the advantages of ChUS, deep lung lesions cannot be evaluated by ultrasound, and there are limitations for several patient groups, such as patients with high body mass index or restricted mobility.

Our study has several limitations: First, we only compare ChUS and CXR and do not provide a gold standard with chest CT imaging. Second, the described lung pathologies on ChUS and CXR are

by no means diagnostic for COVID-19 and could also be found in several other pulmonary conditions such as viral pneumonia, lung embolisms or congestive heart failure. Furthermore, ChUS is highly observer-dependent and can only capture peripheral lung pathologies.

In summary, ChUS represents a useful tool for rapid and informative lung assessment in COVID-19 patients at first clinical presentation and is convenient as a follow-up investigation that could potentially reduce radiation exposure and support clinical decision making. Although ChUS may not be as accurate and sensitive as chest CT scans, it seems to be highly sensitive with respect to detecting peripheral pulmonary pathologies. Further multicenter studies should evaluate the diagnostic power and clinical value of ChUS in the initial assessment and follow-up examinations of COVID-19 patients as well as define criteria regarding whether and when ChUS may replace CXR and/or CT.

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Ethics Approval

The retrospective data analysis was approved by a decision of the local ethics committee № 38/4/20.

Conflict of Interest

The authors report no relevant conflicts of interest.

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